Tuesday, July 28, 1998
CHONDRITES
1:30 p.m. Ussher Theatre

Chairs: R. Hutchison
P. A. Bland

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Classification of 400 Libyan Meteorites

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Alteration Without a Pronounced Oxygen-Isotopic Effect: Implications for Hydration/Dehydration on Primitive Chondrite Parent Bodies

Chikami J.* El Goresy A. Janicke J.
Zinc Concentration in Daubreelites in Enstatite Chondrites: Evidence for Decreasing Abundance in Higher Petrologic Groups and Relative Depletion in Chondrules

Fagan T. J.* Scott E. R. D. Keil K. Cooney T. F. Sharma S. K.
Shock Melting and Mobilization of Feldspar-dominated Liquid in Enstatite Chondrite Reckling Peak 80259

Sexton A. S.* Bland P. A. Wolf S. F. Franchi I. A. Hough R. M. Jull A. J. T. Klandrud S. E. Berry F. J. Pillinger C. T.
Anomalous Chondrites from the Sahara

Schulze H.*
Noble Metal Phases in Rumuruti Chondrites

Folco L.* Mellini M.
La Villa H4 Chondrite: Thermometric Constraints from Enstatite Composition and Microstructure

Hutchison R.*
On the Origin of Tieschitz

Gibson E. K. Jr.* Zolensky M. E. Lofgren G. E. Lindstrom D. J. Morris R. V. Schmidt S. D. Yang S. V.
Monahans (1998) H5 Chondrite: An Unusual Meteorite Fall with Extraterrestrial Halite and Sylvite

Jackel A.* Bischoff A.
Textural and Mineralogical Differences Between LL-Chondritic Fragmental and Regolith Breccias

Reid A. M.* Ayoyama H.
Lewis Cliff 88701: A Partly Equilibrated LL4 Chondrite

Bonino G.* Cini Castagnoli G. Della Monica P. Taricco C. Bhandari N.
Heliospheric Behavior in the Past by Titanium-44 Measurement in Chondrites

Consolmagno G. J.* Britt D. T. Stoll C. P.
Metamorphism, Shock, and Porosity: Why Are There Meteorites?

Benoit P. H. Sears D. W. G.*
The Ghubara L5 Breccia and Its Regolith Maturity

Wacker J. F. Hildebrand A. R.* Brown P. Crawford D. Boslough M. Chael E. Revelle D. Doser D. Tagliaferri E. Rathbun D. Cooke D. Adcock C. Karner J.
The Juancheng and El Paso Superbolides of February 15, 1997, and October 9, 1997: Preatmospheric Meteoroid Sizes

CLASSIFICATION OF 400 LIBYAN METEORITES. D. Weber and A. Bischoff, Institut für Planetologie, Wilhelm-Klemm-Strasse 10, 48149 Münster, Germany (weberd@uni-muenster.de).

Introduction: During the last decade more than 1000 meteorites have been found in the Libyan and Algerian parts of the Sahara. Two extraordinary recovery areas are the Hammadah al Hamra (HH) and Dar al Gani (DG) regions in Libya, where 508 meteorites (DG: 295; HH: 213) have been collected between 1990 and March 1997. At present, four hundred of these samples are classified [1–4] based on detailed mineralogical and chemical investigations. The classifications include the meteorite class but also the degree of shock metamorphism and weathering, the chemical composition of the main phases (usually olivine and Ca-poor pyroxene) and striking petrographic features such as brecciation or the occurrence of shock veins or impact melts.

Results: Among the 400 classified meteorites, 359 ordinary chondrites, subdivided into 200 H, 119 L, and 40 LL chondrites, 30 carbonaceous chondrites, two Rumuruti (R) chondrites, and nine achondrites occur. Detailed petrographical and chemical studies allowed to solve the pairing problem among the carbonaceous and R chondrites and the achondrites. The latter ones comprise five ureilites (two of them paired), two unpaired eucrites, one winonaite, and one lunar meteorite [5]. The R chondrites are not paired, whereas the 30 carbonaceous chondrites represent only six distinct meteorites (two CO3s, two CKs, one Coolidge-type [6], and one unusual C3 meteorite). Pairing among ordinary chondrites, especially for the most common meteorite types such as H5 and L6 chondrites, is not easily to obtain, because there are too many rocks from the same find site showing almost identically mineral compositions and degrees of shock metamorphism and weathering.

Discussion: The classification of a large number of meteorites from one region gives the opportunity to characterize the meteorite population and to compare it with other populations or with the world falls. In the case of the Libyan meteorite population it is first neccessary to solve the pairing problem of the ordinary chondrites before a comparison with other populations can be done. Previous studies [1,7] have shown that the percentage of unpaired Saharan ordinary chondrites can be estimated to be about 60 to 80%. By assuming a value of 40% paired samples the Libyan meteorite population contains 96.5% chondrites (93.0% ordinary chondrites, 2.6% carbonaceous chondrites, and 0.9% R chondrites) and 3.5% achondrites. Compared to the Antarctic meteorite population and the world falls the low abundance or even absence of achondrites, enstatite chondrites, iron and stony-iron meteorites in the Libyan as well as in the Algerian meteorite population [1] is obvious. The lack of enstatite chondrites and stony-iron meteorites can be explained by statistical limits considering the general low abundance of these meteorite types. Iron meteorites could have been collected in the past and used as tools or other objects by the local people. Achondrites may have been overlooked by meteorite searchers due to the terrestrial erosion of the dark fusion crust and the light appearance of the interior of most achondrites.

Summary: The classification of 400 Libyan meteorites does not only result in the recognition of spectacular samples, but also helps to improve the characterization of the Saharan meteorite population. This population shows some slight, but significant differences to the Antarctic population and the world falls which are probably due to special find circumstances and inhabitation of the find area.

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ALTERATION WITHOUT A PRONOUNCED OXYGEN-ISOTOPE EFFECT: IMPLICATIONS FOR HYDRATION/DEHYDRATION ON PRIMITIVE CHONDRITE PARENT BODIES. P. A. Bland[1*], A. S. Sexton[2], I. A. Franchi[2], F. J. Berry[3] and C. T. Pillinger[2], [1]Western Australian Musuem, Perth, WA 6000, Australia, [2]Planetary Sciences Research Institute, [3]Department of Chemistry, [*]Now at: Earth Sciences, Open University, Milton Keynes MK7 6AA, United Kingdom.

Background: Recent work on alteration in unequilibrated chondrites has focused on the CV's, and Allende in particular: a number of petrographic features appear consistent with parent body alteration [1], however, oxygen analyses of matrix separates from Allende do not support this [2].

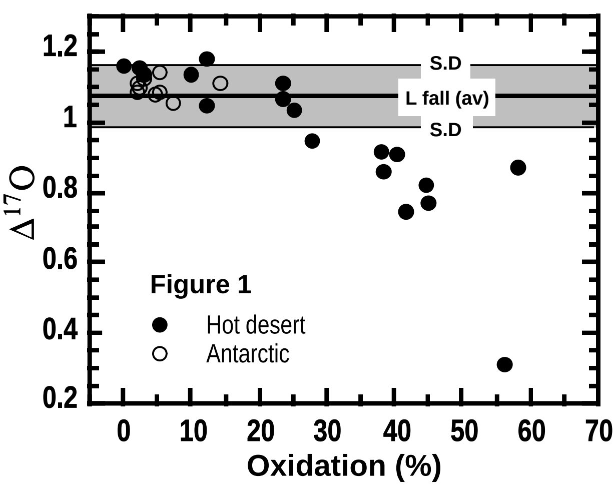
Results: To observe the effect of alteration on the O-isotope composition of meteoritic samples we analysed a suite of L chondrite finds. Oxidation was quantified using ^{57}Fe Mössbauer spectroscopy (based on the proportion of total iron now present as ferric iron). Plotted against Δ^{17}O (Figure 1), this analysis indicates that there is no marked deviation from the average Δ^{17}O value for L group falls [3] until 25% of the iron has been oxidised.

Discussion: Analyses of terrestrial silicates showing incipient alteration reveals that dissolution and crystallisation of secondary minerals occurs throughout the primary grain, not just at grain boundaries. This is especially obvious in olivine, where numerous studies [4–6] report pervasive development of channels a few to a few tens of nanometers wide containing topotactically oriented smectite (where crystallographic orientation is inherited from the primary grain). In these confined spaces the water volume is limited and the ratio of water molecules to surface area is extremely low. Champness [7] observed this type of olivine alteration, interpreting the preferred orientation "in terms of diffusion of cations within a relatively unchanged oxygen framework". This suggests that incipient alteration may occur without a pronounced isotopic effect.

The model: Our analysis supports the interpretation of Krot et al. [1] that fayalitic olivine is the product of a hydration/dehydration event occurring in an asteroidal setting, but suggests a possible refinement. Much of the alteration from primary forsterites occurred in the form of a topotactic restructuring to smectite. Fayalitic olivines formed from a topotactic intergrowth of forsterite and smectite, as the stable product of a heating event which re-ordered the forsterite/smectite structure back to an olivine with a more fayalitic composition. As well as Fe, smectite takes up Al, Cr, Ti and Mn preferentially, so enrichments in these elements in fayalitic olivine [8] are explained, and because the access of bulk water to mineral surfaces is restricted in this type of alteration we do not expect a strong O-isotope effect.

Acknowledgements: Thanks to Jill Banfield, Sasha Krot, and Mike Velbel for constructive remarks and discussions.

References: [1] Krot A. N. et al. (1995). *Meteoritics, 30*, 748. [2] Clayton R. N. et al. (1997). *LPS XXVIII*, 239. [3] Clayton R. N. et al. (1991). *GCA, 55*, 2317. [4] Eggleton R. A. (1984). *Clay. Clay Min.*, *32*, 1. [5] Banfield J. F. et al. (1990). *Contrib. Min. Pet.*, *106*, 110. [6] Hochella M. F. Jr. and Banfield J. F. (1995). in *Chemical Weathering Rates of Silicate Minerals*. (White A. F. and Brantley S. L., eds) Min. Soc. Am., Washington D.C. 353. [7] Champness P. E. (1970). *Min. Mag., 37*, 790. [8] Palme H. and Fegley B. (1990). *EPSL, 101*, 180.



ZINC CONCENTRATION IN DAUBREELITES IN ENSTATITE CHONDRITES: EVIDENCE FOR DECREASING ABUNDANCE IN HIGHER PETROLOGIC GROUPS AND RELATIVE DEPLETION IN CHONDRULES. J. Chikami[1,2], A. El Goresy[2], and J. Janicke[2], [1]Mineralogical Institute, Graduate School of Science, University of Tokyo, Bunkyo-ku, Hongo 7-3-1, Tokyo 113 Japan (chikami@min.s.u-tokyo.ac.jp), [2]Max-Planck-Institut fur Kernphysik, Postfach 103980, 69029 Heidelberg, Germany.

Introduction: Zinc is a moderately volatile element. It is expected to mirror the degree of equilibration in chondritic meteorites. Zn is mainly cited in sphalerite in E-chondrites [1]. However, daubreelite is known to contain various contents of Zn in the EH and EL groups [2]. Most of the petrologic criteria used for the classification of ordinary chondrites are not applicable to enstatite chondrites because textures and mineralogy of the E-chondrites reflect different formational histories [3]. We have conducted a detailed optical, SEM, and electron microprobe study of EH and EL chondrites to assess Zn-bearing sulphide assemblages and study the Zn-distribution in coexisting sulphides, specially daubreelite and sphalerite as a function of petrologic type.

Results: We measured major and minor elements including Zn in daubreelites in ALH 77295, Y 74370, Qingzhen (EH3), St. Marks, Kaidun, Indarch (EH4), and MAC 88180 (EL3). In the EH group there is a clear correlation between the Zn-content in daubreelite and the degree of equilibration. Zinc in daubreelites decreases from EH3 (4.0–8.0 wt%) to EH4 (~1.2 wt%). There is also a difference in the Zn-abundance between daubreelites in EH3 and EL3. Zinc concentration of daubreelites in EL3 (~2.8 wt%) is lower than those in EH3 (4.0–8.0 wt%). Daubreelites coexisting with sphalerite in ALH 77295 have higher Zn-contents (7 w%) than counterparts in the same meteorite not associated with sphalerite (4–5 wt%) in the same meteorite. The Zn contents of daubreelites in the matrix of MAC 88180 are distinctly higher than those in chondrules.

Discussion: Although the highly volatile trace elements show no evidence for a decrease in bulk abundance with petrologic [3], the decreasing Zn-contents of daubreelites from EH3 to EH4 seam to be not related with the abundance of sphalerite in these meteorites. Similar relationships were also found for the EL group (this study, and [2]). During equilibration of E-chondrites Zn diffuses from daubreelite to the coexisting minerals (presumably silicates). This may suggest an increase in fO_2 during equilibration thus leading to incorporation of Zn in silicates as ZnO.

We find evidence for diffusion of Zn from sphalerite to the coexisting daubreelite in ALH 77295 (EH3). Microprobe Zn-profiles in daubreelites display positive concentration slopes to the neighboring sphalerites. In addition, daubreelites coexisting with sphalerites in ALH 77295 (EH3) show higher Zn contents than daubreelites in sphalerite-free assemblages.

The Zn depletion we find in daubreelite grains of chondrules in MAC 88180 is in excellent agreement with previous reports about Zn depletion in bulk chondrules [4–8]. Since chondrules are barren of sphalerite, the depletion of daubreelite in Zn reflects the bulk depletion of this element in chondrules. We interpret this feature as a result of Zn loss in the precursor material during the fusion process of chondrule formation.

Conclusions: (1) Zinc content in daubreelite decreases from lower to higher petrologic types in enstatite chondrites. (2) Zinc diffused from sphalerite to daubreelite in ALH 77295. (3) The low Zn contents in daubreelite in chondrules of MAC 88180 mimics Zn-depletion during chondrule formation.

References: [1] Ramdohr P. (1973) The opaque minerals in stony meteorites, Elsevier. [2] Keil K. (1968) *JGR, 73,* 6945–6976. [3] Zhang Y. et al. (1995) *JGR, 100,* 9417–9438. [4] Grossman J. N. and Wasson J. T. (1985) *GCA, 49,* 925–939. [5] Wilkening L. L. et al. (1984) *GCA, 48,* 1071–1080. [6] Rubin A. E. and Wasson J. T. (1988) *GCA, 45,* 1217–1230. [7] Kallemeyn G. W. and Wasson J. T. (1981) *GCA, 45,* 1217–1230. [8] Schnabel C. et al. (1998) *LPSC XXVIV.*

SHOCK MELTING AND MOBILIZATION OF FELDSPAR-DOMINATED LIQUID IN ENSTATITE CHONDRITE RKPA80259. T. J. Fagan[1], E. R. D. Scott, K. Keil, T. F. Cooney, and S. K. Sharma, [1]Hawai'i Institute of Geophysics and Planetology/School of Ocean and Earth Science and Technology, University of Hawai'i at Manoa, Honolulu HI 96822, USA (fagan@pgd.hawaii.edu).

Introduction: Recent re-examination of several well-known enstatite chondrites has documented that shock-induced whole-rock melting has played a more significant role in the petrogenesis of enstatite chondrites than previously appreciated [1,2]. Here we document shock-induced production and mobilization of feldspar-dominated liquids in the absence of whole-rock melting in the enstatite chondrite RKPA80259. The initial classification of RKPA80259 as the first EL of type 5 focused attention on this meteorite [3], and its classification as an EL has been contended [4-6]. However, shock-melting in RKPA80259 has been noted only recently [2]. Recognition of shock-induced melting of feldspar in RKPA80259 bears on the impact history of enstatite chondrite parent bodies and the role of shock in producing monomineralic veins [7].

Results: Petrographic observations, electron microprobe data, and Raman spectra, taken together, indicate that feldspar in RKPA80259 is a glass that formed from quenching of an impact melt. Feldspathic glass occurs interstitial to enstatite crystals and as veins and linear arrays of inclusions within enstatite. Where the veins and linear arrays cut across the length of an enstatite crystal, vein segments and individual inclusions are elongate parallel to the length of the enstatite prism. Veins and inclusion trails of troilite and metal exhibit similar morphologies and are reminiscent of textures in shocked ordinary chondrites [8]. The small scale of these monomineralic features (typically <200x10 μm) is much less than typically observed for shock-induced whole-rock melting [9].

Electron microprobe analyses indicate the presence of at least two compositional varieties of feldspathic glass. One variety occurs throughout most of the thin section, is approximately stoichiometric, and exhibits a range in composition from Ab60-An37-Or01 to Ab86-An06-Or06. The other variety of feldspathic glass is characterized by excess Si and insufficient alkalies and Al. These nonstoichiometric glasses occur in one portion of the thin section where equant mottled patches of SiO_2 are concentrated. Care was taken during analyses to avoid beam overlap with the SiO_2 patches. Both types of feldspathic glasses are enriched in Mg (~0.1 atom per 8 O).

Discussion: The veins and linear arrays of inclusions of feldspathic glass, troilite, and metal indicate that these phases were injected as melt into fractures in enstatite from interstitial sites during an impact event of at least 30 Gpa [9]. The Mg-rich compositions of the feldspathic glass may have resulted from melting of a small portion of enstatite. The spatial correlation between Si-rich compositions in feldspathic glass and siliceous mottled patches supports the interpretation that feldspathic melt incorporated minor amounts of other silicates, and indicates that feldspar-dominated liquids did not mix on the scale of a thin section.

Implications: The discovery of shock-induced melting of feldspar in RKPA80259 adds to the growing body of evidence that enstatite chondrite parent bodies were subjected to intense bombardment [1,2]. Injection of the feldspar-dominated liquid into fractures suggests that shock melting of individual phases may be a significant mechanism for the origin of monomineralic veins near the surfaces of meteorite parent bodies [7,10].

References: [1] McCoy T. J. et al. (1995) *GCA, 59,* 161–175. [2] Rubin A. E. and Scott E. R. D. (1997) *GCA, 61,* 425–435. [3] Sears D. W. G. et al. (1984) *Nature, 308,* 257–259. [4] Kallemeyn G. W. and Wasson J. T. (1986) *GCA, 50,* 2153–2164. [5] Zhang Y. et al. (1995) *JGR, 100,* 9417–9438. [6] Rubin A. E. et al. (1997) *GCA, 61,* 847–858. [7] Scott E. R. D. et al. (1997) *Nature, 387,* 377–379. [8] Rubin A. E. (1992) *GCA, 56,* 1705–1714. [9] Stöffler D. et al. (1991) *GCA, 55,* 3845–3867. [10] Bischoff A. et al. (1983) *EPSL, 66,* 1–10.

ANOMALOUS CHONDRITES FROM THE SAHARA. A. S. Sexton[1], P. A. Bland[2*], S. F. Wolf[3], I. A. Franchi[1], R. M. Hough[1], A. J. T. Jull[4], S. E. Klandrud[4], F. J. Berry[5], and C. T. Pillinger[1], [1]Planetary Sciences Research Institute, The Open University, Milton Keynes MK7 6AA, UK, [2]Western Australian Musuem, Francis Street, Perth WA 6000; [3]Argonne National Laboratory, 9700 South Cass Avenue, Building 205, Argonne IL 60439-4837, [4]National Science Foundation, Arizona AMS Facility, Physics Building, University of Arizona, Tucson AZ 85721; [5]Department of Chemistry, The Open University, Milton Keynes MK7 6AA, UK, [*]Now at Earth Sciences, The Open University, Milton Keynes MK7 6AA, UK.

Introduction: Over the past few years, well in excess of a thousand meteorite fragments have been recovered from the Saharan desert. This is a report on three unusual chondrites, Sahara 97009 (96g), 97039 (64g) and 97049 (83.4g), which were recovered in April 1997.

Mineralogy and Petrography: In hand specimen the samples exhibit minor brown staining and have surficial fusion crust. In polished thin section each of the samples contain mineral grains and a few chondrule fragments 1-2mm in length. All three samples are brecciated and are petrologic type 6. Olivine and low-Ca pyroxene are the most abundant phases with minor high-Ca pyroxene and plagioclase. Minor undulatory extinction and small irregular fractures indicate a low shock stage for all three meteorites.

Mineral Chemistry: The core compositions of olivines in each of the samples is homogeneous with mean compositions of Fa32.8±0.5 (97009), Fa31.3±0.5 (97039) and Fa33.0±0.8 (97042). Low-Ca pyroxenes show more heterogeneity - Fs28.0±2.0 (97009), Fs26.7±1.9 (97039) and Fs27.0±1.3 (97042). On a Fa vs. Fs plot these data lie beyond the extreme end of the LL chondrite range.

Oxygen Isotopes: A powdered subsample of each meteorite was treated by acid washing in dilute HCl to remove terrestrial weathering products and then analysed by laser fluorination for O isotopic composition. This yielded the following mean values: 97009 - δ^{17}O +4.39 and δ^{18}O +5.14; 97039 - δ^{17}O +4.36 and δ^{18}O + 5.18; 97042 - δ^{17}O +4.62 and δ^{18}O +5.57. The mean Δ^{17}O = 1.70±0.03‰. These values are quite distinct from the LL chondrites, the Δ^{17}O value being 0.3‰ heavier than the heaviest value from an LL chondrite (1), greater than the mean difference between H and L chondrites.

ICP-MS: ICP-MS analyses indicate an overall composition that is not unlike that of LL chondrites (2). However, there are enough differences to suggest that, although broadly similar, these samples are distinct from typical LL composition: Cr, Mn, and Co are all lower than analysed LL's, and Ni is much lower (although it is possible that this may be a weathering effect). In contrast, REEs are all higher than values typical for LL chondrites. Notably, Zn/Mn vs. Al/Mn, which separates the established chondrite groups into distinct compositional clusters, also distinguishes the Saharan finds from LL's: Zn/Mn is higher in all three samples than values for any measured LL.

Weathering: Weathering effects are observable in thin section, in the form of oxide staining and the development of minor veins. ^{57}Fe Mössbauer spectroscopy analysis of the three samples show similar levels of overall oxidation: 23.3±1.7% of the total Fe now present in the ferric form. This is slightly lower than the average value for hot desert finds (3), and it appears unlikely that this level of weathering will have a profound effect on mineral or bulk chemistry. Equally, terrestrial weathering cannot account for the Δ^{17}O values being higher for these samples than for LL chondrites.

These three samples appear to represent a single fall and terrestrial age analyses are in progress in order to confirm this. Whilst one meteorite does not define a new grouplet, the isotopic and chemical compositions of these samples do appear distinct from established ordinary chondrite groups.

References: [1] Clayton et al. (1991) *GCA, 55*, 2317–2337. [2] Kallemeyn et al. (1989) *GCA, 53*, 2747–2767. [3] Bland et al. (1998) *GCA*, in press.

NOBLE METAL PHASES IN RUMURUTI-CHONDRITES. H. Schulze, Museum für Naturkunde, Institut für Mineralogie, Invalidenstrasse 43, D-10115 Berlin, Germany (hartwig.schulze@museum.hu-berlin.de).

Introduction: A characteristic feature of Rumuruti-chondrites is their highly oxidized mineral assemblage. Almost all iron is in the oxidized state. Olivine, when equilibrated, contains on average 39 Mole-% fayalite. Metallic nickel-iron is rare (some tens ppm) and mostly awaruite. Although the bulk chemistry of R-chondrites is not enriched in noble metals [1], under these conditions noble metals form discrete mineral phases as known from the similarly oxidized CK-chondrites [2] and opaque assemblages in Ca-Al-rich inclusions [3]. A few grains in R-chondrites have been described already from Rumuruti [4] and Acfer 217 [5].

Material and methods: Using a SEM with a magnification of 400x, polished thin sections of Rumuruti, Acfer 217, Dar al Gani 013, and Hammadah al Hamra 119 have been systematically scanned for noble metal grains. It is estimated that this procedure revealed almost all noble metal grains equal or larger than 0.5–1 µm. The grains found are mostly 1-2 µm in diameter and rounded. However, they can reach up to 10 × 5 µm with irregular to idiomorphic shapes. Altogether more than 120 grains have been found. The scanned area is approximately 7 cm^2, i.e. there are about 15–20 noble metal grains per cm^2. Their modal abundance is about 1 ppm (by volume). It can be estimated that almost all Os and Pt, and in Rumuruti and Acfer 217 also Ir and Au, is concentrated in these grains. This explains, e.g., the variability of Au [1].

Mineralogy and mineral chemistry: The noble metal mineralogy differs for the investigated R-chondrites. In the R3-6 breccia Rumuruti, the only fall and unweathered sample of this group, PtFe (tetraferroplatinum?) is the most abundant phase. Less abundant, but common are $PtAs_2$ (sperrylite), IrAsS (irarsite), osmium (with up to 10 % Re), and gold. Individual grains of PtSn (niggliite) and Pt_3Sn (rustenburgite) have been found. In the R3-5 breccia Acfer 217 the mineralogy is similar. Most abundant are sperrylite and irarsite. However, PtFe is less abundant and Os often occurs as OsS_2 (erlichmanite) forming solid solutions or intimate intergrowths with RuS_2 (laurite). Both phases were not found in the other R-chondrites. Furthermore, a grain of $PtTe_2$ (chengbolite) has been analysed. In the most unequilibrated R-chondrite Dar al Gani 013, which contains type 3.5-clasts [6], PtFe is by far the dominating phase. Os is common, too. Contrary to Rumuruti and Acfer 217, in DAG 013 sperrylite is lacking and irarsite is very rare. In the R4-chondrite Hammadah al Hamra 119 the situation is different. Os is common. Arsenides (sperrylite and irarsite) are much less abundant. Instead, Pt has an affinity to Sn forming tin phases, especially niggliite. Even sperrylite contains tin. One grain of PdPtSn has been observed.

Petrology: These noble metal grains are dispersed throughout the R-chondrites. In Rumuruti they occur in the dark matrix as well as in the light clasts. Most grains of sperrylite and irarsite were found in the light clasts. Mostly pentlandite and pyrrhotite, either as part of sulfide-feldspar-chromite-aggregates or individual fragments in the matrix, host these phases. PtFe was found isolated in the clastic silicate matrix.

References: [1] Kallemeyn G. W. et al. (1997) *GCA, 60,* 2243–2256. [2] Geiger T. and Bischoff A. (1989) *LPS XX,* 335–336. [3] Bischoff A. and Palme H. (1987) *GCA, 51,* 2733–2748. [4] Schulze H. et al. (1994) *Meteoritics, 29,* 275–286. [5] Bischoff A. et al. (1994) *Meteoritics, 29,* 264–274. [6] Jäckel A. et al. (1996) *LPS XXVII,* 595.

LA VILLA H4 CHONDRITE: THERMOMETRIC CONSTRAINTS FROM ENSTATITE COMPOSITION AND MICROSTRUCTURE. L. Folco[1] and M. Mellini[2], [1]Museo Nazionale dell'Antartide, Università di Siena, Via Laterina 8, I-53100 Siena, Italy (folco@unisi.it), [2]Dipartimento Scienze della Terra, Università di Siena, Via delle Cerchia 3, I-53100 Siena, Italy (mellini@unisi.it).

Introduction: Following our previous works [1-2] on the thermal history of ordinary chondrites, we have undertaken the study of temperature-sensitive chemical composition and microstructures of enstatite from the La Villa, unshocked, H4 meteorite.

Experimental: Pyroxenes from different chondrules and matrix were selected in the petrographic thin sections. The main textural features were determined by optical and Scanning Electron Microscopy (SEM). Microstructures were then investigated using High Resolution Transmission Electron Miroscopy (HRTEM). Chemical compositions were obtained by Electron Micro Probe Microanalysis (EMPA).

Textures: Abundant, well-defined droplet-, compound- and clast-chondrules, set into a microcrystalline matrix characterize La Villa. Textures indicate disequilibrium crystallization, with enstatite crystallizing before augite. Optical (100) striation in enstatite indicates crystallization as protoenstatite, followed by fast inversion to ortho- and/or clinoenstatite upon rapid cooling. (001) fracturing is common.

Geothermometry: Geothermometric estimates were derived on the basis of major element partitioning [3] between enstatite and augite from EMPA data. The minimal crystallization temperature was 1317(50)°C for enstatite and 1211(50)°C for augite, thus consistent with crystallization in the protoenstatite stability field. The Fe/Mg distribution coefficient is typically lower than 1.4, as in terrestrial magmatic rocks [4], thus confirming that both pyroxene compositions were established within igneous environments. In contrast to results from LL chondrites [5], our data from La Villa suggests that the geothermometer can be successfully applied to chondrites.

High Resolution Transmission Electron Microscopy microstructure: Data were obtained for a radial pyroxene chondrule, a poikilitic enstatite chondrule, a microgranular olivine-enstatite chondrule and a large crystal fragment set in the matrix (likely of chondrule origin).

Disorder is maximal in the radial pyroxene chondrule. This chondrule mainly consists of crystalline domains rich in clinoenstatite, elongated some tens of micrometer and arranged in radial fabric. The clinoenstatite domains show extremely frequent [100] stacking faults with clinoenstatite lamellae some unit cells thick interleaved with thinner orthoenstatite lamellae. Clinoenstatite lamellae are either even or odd multiples of the 9Å periodicity and in twin relationship. The coexisting orthoenstatite domains are much more ordered with unfaulted orthoenstatite repeats for up to 2000 Å. Faults are clinoenstatite lamellae which are either even or odd multiples of the 9 Å periodicity; in places clinoenstatite terminates within orthoenstatite with 'U-shaped' and 'Z-shaped' terminations.

The main features are similar in the other specimens. The general microstructural pattern however changes from dominant or abundant clinoenstatite (radial and poikilitic chondrule) to fairly regular (microgranular chondrule) and almost regular orthoenstatite (matrix).

HRTEM images indicate that the (100) ortho-clinoenstatite intergrowth was produced upon rapid cooling across the boundary between the stability fields of proto- and orthoenstatite, namely close to 1000°C. Locally, subsequent reversion from clino- to orthoenstatite produces 'U-shaped' and 'Z-shaped' terminations.

Chondrule cooling rates at ~1000°C: The microstructural pattern occurring in the radial pyroxene and poikilitic chondrule is consistent with primary chondrule cooling: in particular, according to clino- to orthoenstatite reversal experiments [6] they indicate cooling rates of the order of 10°C/hr at ~1000°C. Slightly slower cooling, of the order of 1°C/hr, explains the intergrowth textures found in the microgranular chondrule and matrix.

Therefore, enstatite microstructure indicate that the texturally and compositionally different constituent chondrules of La Villa all cooled fast, but at distinct rates soon after the liquidus-to solidus transition and prior to accretion into parent body. Furthermore, when compared to dynamic crystallization experiments [7], our cooling rates point to nonlinear chondrule cooling histories with cooling rates decreasing with temperature.

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ON THE ORIGIN OF TIESCHITZ. R. Hutchison, Department of Mineralogy, The Natural History Museum, London SW7 5BD, UK.

Introduction: Fractionation of Fe-Ni-Co metal from silicate—the metal-silicate fractionation [1,2]—was reviewed for thirteen chondrite groups using only the mean group compositions from the data of Wasson, Kallemeyn and co-workers [3]. Progressive loss of metal from CI starting material could have led directly to CR, CV, and LL compositions (Fig. 1). Gain of more Ni-rich metal by LL group material could have produced L and H groups. Tieschitz, however, does not lie on this ordinary chondrite (OC) trend (Fig. 1). Its total Fe content, 24.2 wt% [4], is intermediate between L and H groups, but the meteorite could not have been derived by addition or loss of Fe,Ni metal of the composition involved in the OC trend. Evidence is presented that the unique chemical composition of Tieschitz may have been achieved on the parent body some 2 Ga ago.

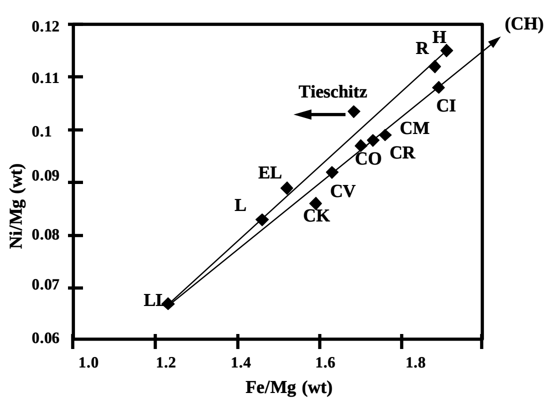

Fig. 1. Metal silicate fractionation in chondrites. Tieschitz is depleted in Fe relative to Ni.

Discussion: Following Kurat [5] and Christophe Michel-Levy [6], Hutchison et al. [7] argued that Tieschitz underwent elemental redistribution by aqueous fluids. The bulk chemical composition [4] indicates that, apart from Fe, Ni, and Co, the meteorite is significantly impoverished only in K, with 505 ppm compared with 782 ppm and 858 ppm in mean H and L group, respectively. Had Tieschitz been derived from starting material on the OC trend (Fig. 1), it must have lost Fe preferentially compared with Ni, which would be expected in loss through leaching. This leads to a paradox. The meteorite has a total Ar-Ar age of 4.45 ± 0.05 Ga [8], but a disturbed stepwise release pattern indicative of "ages" of 5.2–5.6 Ga at low temperatures and 1.6–2.4 Ga at high temperatures. Although the pattern is disturbed, there is no evidence for significant K or Ar loss. Indeed, the data may be interpreted in terms of partial resetting of the K-Ar chronometer 2 Ga ago, consistent with an event at 2.04 ± 0.13 Ga recorded by the Sm-Nd system [9].

Conclusion: It is possible that Tieschitz acquired its abnormal total Fe content by a parent body process only 2 Ga ago. If so, loss of 3 wt% Fe must be reconciled with total K and Ar retention in the same process, presumably aqueous alteration. Questions then arise - Did other aberrant chondrite groups, such as CK, acquire their total Fe through a planetary process and, if so, when?

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MONAHANS (1998) H5 CHONDRITE: AN UNUSUAL METEORITE FALL WITH EXTRATERRESTRIAL HALITE AND SYLVITE. E. K. Gibson Jr.[1], M. E. Zolensky[1], G. E. Lofgren[1], D. J. Lindstrom[1], R. V. Morris[1], S. D. Schmidt[2], and S. V. Yang[3], [1]SN2, NASA Johnson Space Center, Houston TX 77058, [2]Marian Blakemore Planetarium, Midland TX 79701, and [3]Lockheed Martin, NASA-JSC, Houston TX 77058.

At 6:48 p.m. CST March 22, 1998, the citizens of Monahans, Texas, were subjected to a fireball, observed over a 150-mile swath surrounding the town, and two sonic booms followed by rumbling accompanied by a large dust train. Two stones, which landed on city streets, were collected. One (1243 gm), which landed 40 feet from where 8 boys were standing made a penetration crater 4 inches deep in loose sand and was slightly warm to the touch when recovered within 1–2 minutes of fall. Coordinates of the fall site are 102°53'30"W and 31°36'30"N. The other stone (1344gm) was recovered 800 feet SSE of the first site the following morning. It was collected 10 feet from the penetration crater (4 × 5 × 2 in. deep) it made in an asphalt street. A section of the asphalt street was removed to preserve the crater. No additional meteorites have been located. Specimens are completely covered with fusion crust except where small chips were broken upon impact or prior to collection by the Monahans police. The meteorite is named Monahans (1998), because an Fe meteorite, Monahans (1938), was found previously.

Within 50 hours of fall, both meteorites were analyzed in NASA-JSC's low-background counting facility. In addition to natural K, U, and Th, gamma-ray spectra contained peaks from a variety of cosmic-ray-produced radioactive nuclides including ^{7}Be, ^{22}Na, ^{26}Al, ^{46}Sc, ^{48}V, ^{51}Cr, ^{54}Mn, and $^{56,57,58,60}Co$. Because sample counting began within 50 hours of fall, nuclides with short half lives (5.6-day ^{52}Mn and even 15.0-hour ^{24}Na) were observed. Estimates of decay rates require preparation of mockups, in progress.

A chip consisted of white and black lithologies set within a grey, clastic matrix. Electron microprobe and petrographic data indicate both lithologies are H5, with the black lithology being slightly more equilibrated and considerably more shocked (S2 vs S4). Reflectivity spectra of coarse powder display the two-band structure (minima at 940 and 1930 nm) characteristic of orthopyroxene. Mössbauer spectra of the same powder showed a composite pattern consistent with the presence of ferrous iron in olivine, orthopyroxene, and troilite and metallic Fe in a Fe/Ni alloy. No ferric Fe was observed.

Matrix consists of a pulverized mixture of the white and black lithologies, with one exception: grains 0.5–3 mm of a dark blue to purple, vitreous, transparent to opaque mineral were present. EDX and WDS analysis showed it to be halite (NaCl), with minor inclusions of the related halide sylvite (KCl). To our knowledge, this is the first report of these minerals within an ordinary chondrite, and they appear to represent the coarsest examples known from any meteorite. Halite and sylvite have been previously reported in a ureilite and the Murchison carbonaceous chondrite.

Several interesting possibilities are suggested by the halite occurrence in Monahans (1998): (1) The most likely paragenesis for the halite is from asteroidal brines. If this origin is correct, then fluid inclusions may be present within the salt crystals. (2) If brines were responsible for the halite/sylvite, then other traces of aqueous alteration may be present. (3) Halite was noticed in Monahans (1998) because of its blue/purple color, and this permitted special sampling and thin sectioning procedures to be employed which preserved the halides. Exposure of the meteorite to a humid environment would certainly have caused dissolution of the halite/sylvite, and bleaching of the halite. If not noted within a few days of its fall, any halite present in a chondrite may be routinely overlooked or destroyed.

Acknowledgments: We thank the residents and city council of Monahans, Texas, for the opportunity to examine the meteorite in a timely manner.

TEXTURAL AND MINERALOGICAL DIFFERENCES BETWEEN LL-CHONDRITIC FRAGMENTAL AND REGOLITH BRECCIAS. A. Jäckel and A. Bischoff, Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Strasse 10, D-48149 Münster, Germany (jackel@nwz.uni-muenster.de).

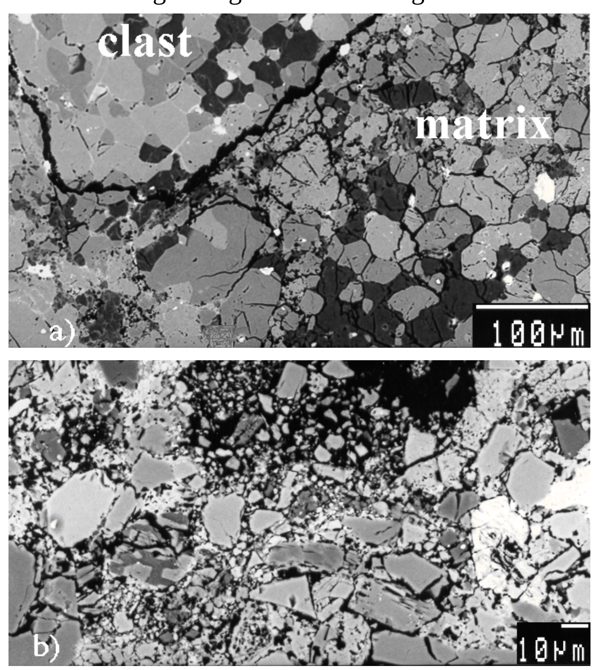
Introduction: Sixteen LL-chondritic breccias were studied in detail in order to obtain more information about the complex processing and reprocessing of material on the LL-chondritic parent body. Compared to H- and L-chondrites it is generally noticed that LL-chondrites are often brecciated [1]. These breccias are characterized by different types of mm-sized fragments embedded within a fine-grained matrix [2]. Essentially, two different types of breccias can be distinguished: regolith breccias and the more abundant fragmental breccias. Regolith breccias derive from the uppermost surface material of the parent bodies containing significant concentrations of solar wind implanted noble gases as well as preirradiated mineral grains. Fragmental breccias represent material that was shielded from irradiation and does not contain solar wind implanted noble gases.

Results: Polished thin sections of twelve LL-chondritic breccias from the Algerian and Libyan part of the Sahara (Acfer 066, 091, 112, 160, 175, 193, 251, Hammadah al Hamra 052, 057, 060, Dar al Gani 054 and 062) as well as the samples of Adzhi Bogdo (Mongolia), Jelica (Serbia), Parambu (Brasilia), and St. Mesmin (France) were studied by SEM and with an electron microprobe. The textures and mineral compositions of different types of fragments (e.g., metamorphosed clasts of petrologic type 6, impact melt rock clasts, potassium-rich fragments, breccias that occur as individual clasts, dark lithic clasts, unequilibrated fragments and Ca,Al-rich fragments) were investigated. A characterization of the most common types of fragments and of the fine-grained matrix were already given in [2–4].

Based on mineralogical observations, track studies, and noble gas analyses [5], the meteorites have to be subdivided into regolith breccias and fragmental breccias. In all breccias except Acfer 066 and Adzhi Bogdo, both, matrix olivines and olivines in the diverse lithologies are similar in composition and well equilibrated. These breccias do not contain solar wind implanted noble gases, preirradiated mineral grains, and show a fine-grained recrystallized matrix consisting of subrounded grains with approximately 120° triple junctions (Fig. 1a). Based on these features it has to be concluded that brecciation in these fragmental breccias took place during or before metamorphism. On the other hand, the two breccias Acfer 066 and Adzhi Bogdo were identified as regolith breccias containing preirradiated mineral grains, noble gases, and a clastic matrix (Fig. 1b). The chemical compositions of the matrix olivines in regolith breccias vary unlike the composition of matrix olivines in fragmental breccias. The occurrence of clasts showing different olivine compositions indicates that equilibrated and unequilibrated lithologies were mixed together by impact events after the equilibrated and recrystallized fragments were formed by thermal metamorphism.

Conclusions: Considering the matrix texture of the studied LL-breccias clear distinction between fragmental and regolith breccias is possible. The loss of the clastic and porous matrix due to metamorphism and recrystallization in fragmental breccias is a fundamental difference between both types of breccias.

Fig. 1. Typical matrix textures of fragmental breccias **(a)** and regolith breccias **(b)** The recrystallized matrix in Acfer 193 consists of subrounded grains with nearly 120° triple junctions (Fig. 1a). Fig. 1b illustrates the clastic and porous matrix of the regolith breccia Acfer 066 consisting of angular mineral fragments.



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LEW88701, A PARTLY EQUILIBRATED LL4 CHONDRITE. A. M. Reid[1,2] and H. Ayoyama[2,3], [1]Department of Geosciences, University of Houston, Houston, TX 77204-5503, areid@uh.edu, [2]Lunar and Planetary Institute, Houston, TX, [3]University of Tokyo, Japan.

Introduction The Antarctic meteorite LEW88701 has well-developed chondritic texture, the olivine is of near constant composition, and a significant number of the low calcium pyroxenes are multiply twinned. High calcium pyroxenes are not abundant and the feldspathic component occurs as very fine-grained aggregates. Petrographically and mineralogically LEW88701 is an LL4 chondrite. However the low calcium pyroxenes encompass a significant range of Fe/Mg ratios and the thin section LEW8701,3 contains a grain of high Mg olivine that is only partly transformed to the more Fe-rich, dominant composition.

Olivine Most olivine grains are very close to the average value of $Fo_{71.5}$. Multiple analyses give values for FeO and MgO of 25.88 +/- 0.39 and 36.47 +/- 0.45, respectively, comparable to average olivine values for 8 Antarctic LL4 chondrites of 25.08 and 36.88. One olivine grain (~ 1mm long) has core compositions with FeO 5.54 and MgO 53.45, corresponding to $Fo_{94.5}$. Along the margins of the grain, and along fractures within the grain, the composition is more Fe-rich, attaining compositions that match the other olivines in the meteorite. Intermediate compositions occur in the transition regions and gradients can be mapped along the narrow transition zones. It appears that this larger olivine is a relict grain that has partly transformed to a more Fe-rich composition, identical to those in the bulk of the meteorite.

Low calcium pyroxene In contrast to the olivines, the low calcium pyroxenes span a range from slightly more Fe-rich than the average LL4 low calcium pyroxene to values that are substantially more Mg-rich ($Wo_{0.3}\,En_{88.4}\,Fs_{11.3}$ to $Wo_{2.0}\,En_{74.4}\,Fs_{23.6}$). In comparison to the olivine analyses, the standard deviations for multiple low calcium pyroxene analyses are significantly larger (average FeO 12.59 +/- 2.35, MgO 30.40 +/- 2.07).

Discussion LEW88701 appears to be a transitional meteorite in which the bulk of the olivine has been transformed to a constant composition of $Fo_{71.5}$. In larger grains (Figure 1) the transformation is incomplete leaving cores of a magnesian precursor olivine altered to more Fe-rich olivine along the grain margins and adjacent to fractures. Evidence for this process is only locally preserved where the transformation has not gone to completion. In contrast to the near complete homogenization of the olivines, the low calcium pyroxenes maintain a compositional spectrum derived from the precursor materials. The distribution of the more Fe-rich regions of the relict olivine grain is shown in a back-scattered electron image in Figure 1. This distribution has been confirmed by using the electron microprobe to construct element distribution maps of the grain and surrounding areas. The pattern is consistent with the introduction of iron from the surrounding matrix, and preferentially along fractures within the olivine. The present status of these fractures is that they are marked by the presence of thin seams comprising metal and sulfide. The Fe-rich regions within the olivine are immediately adjacent to the metal/sulfide veinlets. The transformation of the original magnesian olivine has been achieved through the introduction of iron derived from fractures wherein iron is now present as metal and sulfide. This occurrence may thus provide an insight into the metamorphic process that transformed the silicates, and provides evidence that the change in olivine composition in the ordinary chondrites occurs not solely through the diffusion of iron through the silicate lattices, but is accelerated by the movement of iron (and nickel and sulfur) as a fluid, probably a vapor, through the minute passageways afforded by fractures in the meteorite.

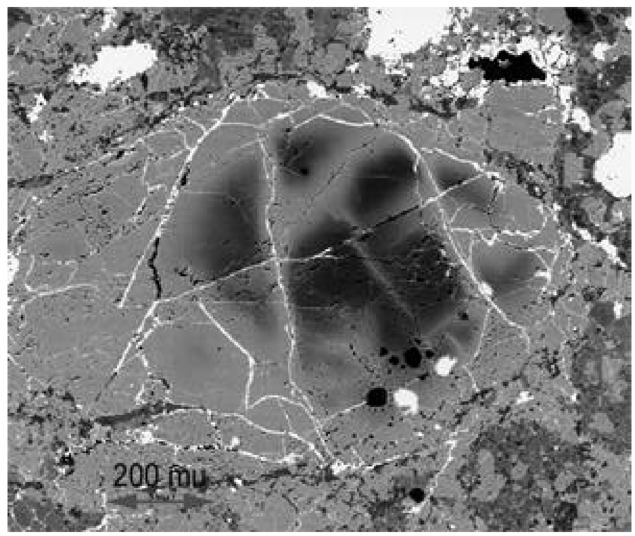

Figure 1: Back scattered electron image of a portion of LEW88701. Relict olivine grain with Mg-rich core (darker) and Fe-rich regions that are adjacent to the margins and to fractures containing metal and sulfide (brightest regions).

HELIOSPHERIC BEHAVIOR IN THE PAST BY TITANIUM-44 MEASUREMENT IN CHONDRITES.

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The only cosmogenic radioisotope in meteorites, suitable to investigate the century scale galactic cosmic ray (GCR) variability and consequently the heliospheric behavior, is $^{44}Ti(T_{1/2}$~60y). It is produced in GCR interactions in meteoritic Fe and Ni. Its production rate in chondrites is very low [1]. In the last years we measured the γ-activity of several meteorites in our underground station in Torino. For this purpose we developed a highly sensitive and selective Ge-NaI (Tl) system, designed and set up to measure, in particular, the very low activity of ^{44}Ti in meteorites. To evaluate the ^{44}Ti with non-distructive technique we measure the γ-activity at 1157 keV of its daughter $^{44}Sc(T_{1/2}$ = 3.93 h). The background, in 1157 keV peak, is ~0.6 count/day in the Ge-NaI coincidence mode, adopted for the ^{44}Ti(^{44}Sc) measurements.

We measured so far the ^{44}Ti activity of thirteen chondrites, which fell in the interval 1840–1996. To determine the production rate, it is necessary to correct the measured activity for target element (Fe and Ni) abundances, for shielding depth within the meteoroid and to calculate the activity at the time of fall. The shielding correction is made by measurements of the density of tracks produced by CR heavy nuclei. These measurements indicated that the changes in the ^{44}Ti production rate with depth is small for relatively small bodies, as expected for high energy product. In these cases there is a good agreement for production rate and shielding corrections between different models [1,2]. However for meteorites that were estimated as large bodies in space there is a discrepancy for shielding correction between the two models. This holds for Olivenza, Dhajala, Mbale. To disentangle this problem we planned to measure the ^{44}Ti in different fragments at different shielding.

In order to determine the ^{44}Ti activity at the time of fall the half life of this radioisotope is crucial. It enters also in calculating the number of nuclei from the activity measurement. We adopted so far the most recent value, $T_{1/2}$ = 66.6 y [3]. Very recently this value has been revised to $T_{1/2} = 59.2 \pm 0.6$ y on the basis of the measurements of ^{44}Ti decay, performed in different Laboratories, among which ours [4].

Recently we measured the ^{44}Ti activity in Kernouvé, which fell in 1869 and Grueneberg (1841), kindly provided by Dr. R. Schmitt. On the basis of preliminary tracks measurements we deduce that they were small bodies in space; therefore, their shielding correction is small. Grueneberg had a ^{44}Ti activity which agrees with that of Cereseto (1840) and Kernouvé had an intermediate activity among these and those of Alfianello (1883), Lancon (1897), and Holbrook (1912). Therefore the new results confirm and reinforce the reliability of the ^{44}Ti profile obtained previously.

On the basis of the ^{44}Ti activities of small bodies, deduced by the new half life of 59.2 y we obtain a profile with a maximum (~1840) in Cereseto and Grueneberg and another broad maximum in Rio Negro (1934) and Monze (1950). These two maxima occur after a lag of 30–40 y since the prolonged solar minima (GCR maxima) of Dalton (~1800) and Modern (~1900) as would be expected by calculations, since ^{44}Ti production integrates over a few half lives before the meteorite fall. The phase of the observed maxima agrees with that calculated, but the magnitude of increase (25–30%) is four times higher than expected from GCR modulation deduced solely by the sunspot number series [5]. Therefore we infer that during prolonged (Dalton and Modern) solar minima the heliosphere allowed a higher GCR flux than at the recent observed minima of the 11 y sunspot cycle.

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METAMORPHISM, SHOCK, AND POROSITY: WHY ARE THERE METEORITES? G. J. Consolmagno SJ[1,2], D. T. Britt[2], and C. P. Stoll[3], [1]Vatican Observatory, Steward Observatory, University of Arizona, Tucson AZ 85721 (gjc@as.arizona.edu), [2]Lunar and Planetary Lab, University of Arizona, Tucson AZ 85721, [3]6270 Colby, Oakland CA 94628.

Introduction: Most carbonaceous chondrites appear to have relatively large porosities, in the range of 20% to 38% [1,2] (a handful of CVs are exceptions). Most ordinary chondrites, after correcting for terrestrial weathering, have porosities between 8% to 12% [1]. Porosity is not a function of petrographic grade [1,3]. The average porosity is about 12% for shock state S1 chondrites, and 10% for all other shock states [1,4]. But a relatively small number of lightly shocked ordinary chondrites have porosities ranging up to 30%; the maximum value of this range appears to decrease linearly with increasing shock state — ordinary chondrites of shock state S3 can still range in porosity up to 20%, but the highest porosity of an S6 meteorite is only 10% [1].

Chondrites resemble terrestrial sandstones in that they were formed by the physical accumulation of unrelated grains, followed by a lithification process. Tectonics and the simple weight of overlying layers provide the conditions for lithification of sandstones on Earth. What role does this play on meteorite parent bodies? Why do ordinary chondrites exist as well-compacted rocks? Why are carbonaceous chondrites less well compacted?

Porosity and Pressures: Sandstones have porosities ranging from 15% to 30%. Experiments [5] show that confining pressures of 0.3 to 0.4 GPa are required to fill their pore spaces with comminuted rock; such material is still filled with microcracks and still has a significant porosity. By comparison, the central pressure of the largest asteroid, Ceres, is about 0.2 GPa. We conclude that the lack of correlation between metamorphic state and porosity is not surprising; no asteroid is large enough for burial depth to change porosity.

Hirata et al. [6] found that mineral powders (initial porosity 30% to 35%) shocked to 2.5 GPa reduce their porosity to about 10%. Increasing the shock pressure only slightly decreases porosity from this point. These data closely parallel our average meteorite porosity vs. shock-state trends. This is consistent with the idea that impact processes in the early solar system are a source of compaction for the ordinary chondrites. On the other hand, in this scenario the persistence of some high porosity meteorites, both occasional ordinary chondrites but especially most C type meteorites, is surprising.

Speculation: The initial compaction of meteorites may have occurred due to collisions at relatively slow impact velocities; a meteoroid at a relative speed of 1.2 km/s has a kinetic energy density equivalent to 2.5 GPa. After Jupiter's formation, its gravity would accelerate impactors in the asteroid belt. Resulting higher-velocity shocks, including the shock event that finally launched the meteoroid from its parent body to an Earth-intersecting orbit, may have provided the shock features seen in most meteorites today. (S3 is the most common shock state [7]). For C types, fluid in the pore spaces (water or other ices) may have prevented shock compaction, while the shock mobilized this water for aqueous alteration. Few C meteorites with high shock state have been found; their porosity may have inhibited the transmission of shock, or the survival of the target material, during these high-velocity collisions.

An alternate scenario is also possible: today's asteroids may simply be the surviving cores of much-larger proto-asteroids whose surfaces were disrupted and dispersed by collision early in the solar system's history.

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THE GHUBARA L5 BRECCIA AND ITS REGOLITH MATURITY. P. H. Benoit and D. W. G. Sears, Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville AK 72701, USA (COSMO@uafsysb.uark.edu).

The Ghubara meteorite was found in the deserts of Oman in 1954 and described as a 226 kg black L5 chondrite with "unequilibrated host" (Fa_{22-27}) and "equilibrated xenoliths" (Fa_{24}) [1]. The meteorite is gas-rich [2], and it is clear that Ghubara is a regolith breccia with dark matrix and light clasts. Haq et al. [3] previously showed that induced thermoluminescence (TL) measurements can provide an estimate of the maturity of regolith breccias, so we measured the induced TL properties of eight matrix samples and nine samples of light clasts from Ghubara. The samples were taken from three cores and were supplied to us by M. E. Lipschutz.

Our TL sensitivity data are shown in Fig. 1. While there is a certain amount of overlap, the matrix samples have lower TL sensitivity than the clast samples (means $\pm 1\ \sigma$ are 0.53 ± 0.09 and 0.7 ± 0.1, respectively), with the averages giving a matrix/clast ratio of 0.76. The matrix to clast TL sensitivity ratio for ordinary chondrite regolith breccias varies from 1.0 to 0.1 in a log-linear fashion with increasing regolith maturity when compared with other indices of maturity (volatile trace element and carbon abundances). Thus a value of 0.76 indicates a moderate degree of maturity. Also consistent with moderate maturity, the induced TL peak temperature and peak width data for the clasts and matrix are similar, whereas for mature regoliths the matrix tends to have broader peaks at lower peak temperatures compared with the clasts.

While solar trapped gas abundance and carbon content increase with regolith maturity, in the case of a find like Ghubara the data can be compromised by weathering which causes the loss of trapped gasses, the trapping of atmospheric gases [4] and contamination with terrestrial carbon. The ratio of TL sensitivity values for the matrix and clasts is independent of weathering. The ^{20}Ne, ^{36}Ar, and C contents of Ghubara are consistent with a moderate degree of maturity, in agreement with the induced TL data, but ^{4}He data suggest a highly immature regolith. However, literature values for ^{4}He are in poor agreement and this light inert gas is especially prone to redistribution during weathering. We suggest that Ghubara is a regolith breccia of moderate maturity, comparable to St. Mesmin and less mature than Leighton (TL sensitivity matrix/clast ratios of 0.63 and 0.28, respectively).

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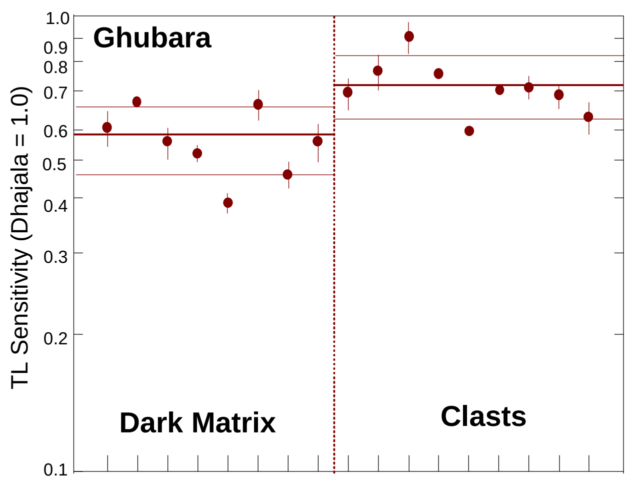

Fig. 1. TL sensitivity values (Dhajala normalized) for matrix and clast samples of the Ghubara regolith breccia.

THE JUANCHENG AND EL PASO SUPERBOLIDES OF FEBRUARY 15 AND OCTOBER 9, 1997: PRE-ATMOSPHERIC METEOROID SIZES.

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On February 15, 1997 at ~15:23:35 UT (during the hour before midnight local time) a fireball occurred over Shandong Province, China with an extended terminal burst probably exceeding magnitude -20 near 35.5° N, 115.6°E. The fireball was observed in the infrared by detectors located in Earth orbit (e.g., 1). Numerous H5 chondrite meteorites fell spectacularly at Juancheng in a strewnfield ~10.5 X 4.3 km oriented roughly E-W (2). The Juancheng meteoroid was thoroughly fragmented yielding >1,000 individuals massing more than 100 kg in total, but with the largest recovered individual of only 2.6 kg. Counting of radiogenic cosmogenic nuclides in eight individuals of 0.13 to 0.25 kg yields initial results as follows: ^{60}Co ($t_{1/2}$ = 5.3 a), 9.7 - 139.3 dpm/kg; ^{22}Na ($t_{1/2}$ = 2.6 a), 89.2 - 121.6 dpm/kg; ^{26}Al ($t_{1/2}$ = 704 ka), 52.5 - 67.7 dpm/kg. The largest ^{60}Co activity requires minimum and maximum radii of ~0.45 and 1.5 m (~1,000 to 50,000 kg) respectively (3, 4). Greater ^{60}Co activities in chondrites have been reported only from the Allende and Jilin meteorites. The ^{26}Al and ^{22}Na activities are less sensitive to minimum size, but, as these activities are nearly constant though much of sizable meteoroids' radii, an upper limit and required radii of 0.65 to 0.85 m (4,000 to 9,000 kg) are set (5). The ^{26}Al activities' average (63.7 vs. 63.5 dpm/kg) equals that of the St-Robert H5 chondrite (6, 7), but the maximum values are lower and less variation is observed indicating a larger pre-atmospheric object than the ~0.5 m radius (~2,000 kg) estimated for St-Robert (6, 7, 8). The average ^{22}Na/^{26}Al ratio is 1.72 vs. 1.54 for St-Robert. Given that this ratio can vary by 1.5 times over the solar cycle (9), and that the Juancheng fall occurred ~2.7 years or one ^{22}Na half life after the St-Robert fall during a period of quiet sun, the ~12% increase is expected. As the activities of ^{26}Al are in equilibrium with those of the ^{22}Na, a cosmic ray exposure age of >~2 Ma is indicated for the meteoroid. ^{60}Co vs. ^{26}Al activities follow predicted behaviour for spherical meteoroids.

On October 9, 1997 at ~18:47:15 UT (during the local noon hour) a large fireball appeared near the Chihuahua, Mexico - Texas, USA border moving northwards to detonate east of El Paso, TX. The fireball's terminal flare exceeded -20 magnitude (-23 to -24 for observers near the explosion) and the seismic wave was strong enough to break glass in rare cases. The location and time of the terminal explosion are well determined by eyewitness reports, videos (6 recd.) and photographs (18 recd.) of the resulting dust cloud, seismograph recordings (~12) of the blast wave, three infrasound detections, and detections by infrared sensors located in Earth orbit (e.g, 1). This location is 31.80 N, 106.06 W at ~28.5 km altitude. Infrasound records indicate an energy released in the terminal burst of 0.05 - 0.5 kilotons (0.2 - 2 X 10^{12} J). The provisional calibration of energy released to induced ground motion derived for the St-Robert fireball (7) indictates an energy release at the top end of this range. The fireball trajectory derived is within 10° of motion towards 003° with an elevation angle of ~65°. Radiants within this range require entry velocities of ~25 km/s for objects from ~2.5 AU indicating that 5 to 10 tonnes was pulverized in the terminal burst. No meteorites have been found to date for this object estimated at originally ~2 m and 10–20 tonnes.

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